Ia. \[ \mu = iA \]
if current caused by a charge \( e \), moving with speed \( v \)
in a circle of radius \( r \), then
period = \( 2\pi r/v \)

\[ i = \frac{e}{(2\pi r/v)} \quad A = \pi r^2 \]

\[ \mu = \frac{e}{(2\pi r/v)} \quad \pi r^2 = \frac{e v r}{2} \quad m = \frac{e r m v}{2m} = \frac{eL}{2m} \]

from classical to quantum mechanical

\[ L = \hbar \]

\[ \mu = \frac{e\hbar}{2m} \]

Ib. Neutron is composed of up and down quarks (udd)
Quarks carry charge \( u = +\frac{2}{3}e \)
\( d = -\frac{1}{3}e \)
The charged nature of sub-nucleonic particles produce a non-zero \( \mu \) for neutron

Ic. Again, both protons (uudd) and neutrons (uudd)
are composed of quarks. Since nucleons are not point particles, they deviate significantly from the Dirac expectation.
IIa. $^2\text{H}$, 1 proton, 1 neutron

Naively, we assume that $\mu$ is combination of spin and factors of proton and neutron:

$$\mu = \frac{1}{2} (g_s(p) + g_s(n))$$
$$= \frac{1}{2} (5.8856 + (-3.826))$$
$$= \frac{1}{2} (1.7596) = [0.8798 \mu N]$$

IIb. $\psi = a_s \psi_{l=0} + a_d \psi_{l=2}$

$$\mu = a_s^2 \mu_{l=0} + a_d^2 \mu_{l=2}$$

IIc. $^2\text{H}$ measured by molecular beam magnetic resonance method. See Kellogg, Rabi, Ramsey ad Zacharias PR 57, 677 (1940)

Static magnetic field \{ search for absorption of varying rf field \} rf photons

IId. $^{20}\text{Ne}_{10}$ magnetic moment is zero since all protons and all neutrons couple to $J=0$ in the ground state. (strong p-p and n-n pairing)
III a. \( \frac{Q}{\alpha} = 4.20 \text{ barns} \)

What are \( a + c \) ?

2 equations:

\[
\frac{Q}{\alpha} = \frac{2}{5} e^{-1} (a^2 - c^2)
\]

\[
R^2 = \frac{1}{2} (a^2 + c^2) = 1.2 \text{ fm} \ A^{2/3}
\]

\[
\frac{4.2 \times 10^{-24} \text{ cm}^2}{93} \left( \frac{5}{3} \right) = (a^2 - c^2) = 1.438 \times 10^{-25} \text{ cm}^2 \left( \frac{10^{-2} \text{ cm}}{10^{-2} \text{ m}} \right)^2 = 1.438 \times 10^{-29} \text{ m}^2
\]

\[
2 \times 1.2 \times 10^{-30} \text{ m}^2 (181)^{2/3} = (a^2 + c^2) = 7.679 \times 10^{-29} \text{ m}^2
\]

\[
a^2 - c^2 = 1.438 \times 10^{-29} \text{ m}^2
\]

\[
a^2 + c^2 = 7.679 \times 10^{-29} \text{ m}^2 = 2c^2 + 1.438 \times 10^{-29} \text{ m}^2 = 7.679 \times 10^{-29} \text{ m}^2
\]

\[
a^2 + (5.58 \times 10^{-15} \text{ m})^2 = 7.679 \times 10^{-29} \text{ m}^2
\]

\[
a^2 + 3.1205 \times 10^{-29} \text{ m}^2 = 7.679 \times 10^{-29} \text{ m}^2
\]

\[
c = 3.1205 \times 10^{-29} \text{ m}^2
\]

\[
c = 5.58 \times 10^{-15} \text{ m}
\]

\[
a = 6.751 \times 10^{-15} \text{ m}
\]

\[
\frac{a}{c} = \frac{6.751 \times 10^{-15} \text{ m}}{5.58 \times 10^{-15} \text{ m}} = 1.21
\]

III b. For the numbers 8, 20, 28, 50, 82, 126, there is a large gap in single-nucleon shell structure. These "magic" nucleon numbers show extra "stability." Therefore, they are spherical in shape and should have \( Q = 0 \).
IV a. 

[Diagram of a neutron with u and d quarks]

Size: $1 \times 10^{-15}$ m (1 fm)

Charges: $u = \frac{2}{3} e$

$d = -\frac{1}{3} e$ (each)

If full separation of u and d quarks in nucleus, then

$$d = \frac{q \Delta z}{\varepsilon}$$

$\varepsilon$ is separation distance

$$d = \left[ \frac{2}{3} - \left( -\frac{2}{3} \right) \right] e \left( 1 \times 10^{-13} \text{ cm} \right)$$

$$= \frac{4}{3} e \left( 1 \times 10^{-13} \text{ cm} \right) = 1.33 \times 10^{-13} \text{ e cm}$$

(Actual size is $\leq 10^{-26} \text{ e cm}$)

IV b.

C = charge conjugation symmetry

P = parity change symmetry

T = time reversal symmetry

CP broken in decay of neutral meson.

T is expected to be broken if CPT is an exact symmetry.

Evidence for neutron EDM would violate T symmetry.